Observations of the Spots and Markings on the Planet Jupiter, made at the Dearborn Observatory, Northwestern University, Evanston, U.S.A. By G. W. Hough, Director.

The observations for longitude, latitude, and magnitude of objects on the planet *Jupiter* have all been made with the parallel wire micrometer, preferably near the central meridian, but no rigid rule is followed in this respect. The longitude and latitude are usually determined whenever the spot or marking is wholly on the disc and distinctly visible.

The longitudes are ascertained by measuring the distance of the apparent centre of the object from the two limbs of the planet, according to the method I pointed out some years ago. A determination of longitude or latitude generally consists of three bisections of the object and each limb of the planet. In the case of longitude, one-half of the difference of the distances at the mean of the times is the distance of the apparent centre of the object from the central meridian of the visible disc. This method of determining longitudes has been found to be greatly superior, in point of accuracy, to the method of transits, as well as a great saving of time.

Professor Barnard, of the Lick Observatory, in the publications of the Astronomical Society of the Pacific, No. 5, and in the *Monthly Notices of the Royal Astronomical Society*, 1891 November, on insufficient data, has too hastily assumed that the method of eye estimates, or transits, may be as accurate as micrometer work.

My observations on the planet *Jupiter* with the 18½-inch refractor of the Dearborn Observatory have been continuous since 1879, with the exception of the opposition of 1888 and a portion of 1889, during which period the telescope was dismounted for removal to the new site at Northwestern University.

The great red spot, owing to its long period of visibility, is perhaps the most interesting object on the disc. Since its observation in 1878, *Jupiter* has made a complete revolution in his orbit, and the red spot appears to have preserved its outline, shape, and size with very little change during the whole period. There has been marked fluctuation, however, in its colour and visibility, the spot at times being so faint as to be invisible with small telescopes.

During the past twelve years a number of observers have asserted at different times that the red spot was connected with, or merged into, a belt in its immediate vicinity. This matter was fully discussed some years ago, and I inferred from what was then said that it was the general opinion of all astronomers who used sufficient optical power, that the spot was at all times separate, although in close proximity to other matter.

During 1889 and 1890 the planet was too far in south declination to afford any definite information. So far as my

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observations go, however, the spot has always been distinct and separate from surrounding matter, apparently exerting a repelling force, as I stated in my Annual Report for 1883.

During the past opposition, under favourable conditions the spot was noted as pale pink, being similar in tint to what it was in 1879–80, but the colour was not so intense. The spot this year was not so strongly defined as the equatorial belt.

In the comparison of observations for latitude, made in different years, it is more convenient to use the distance from the equator expressed in seconds of arc, reduced to mean distance.

If the Jovicentric or Jovigraphic latitude of a spot is given, one does not know where to look for it on the disc unless the latitude is reconverted into seconds of arc.

I have, therefore, added the reduced latitude, obtained by applying the correction for the elevation of the Earth above *Jupiter's* equator. This correction is given in degrees in Marth's invaluable Ephemerides, published annually in the *Monthly Notices* of the Royal Astronomical Society.

In computing the correction to be applied to the apparent latitude, I have used the values $18''\cdot33$ and $19''\cdot48$ for the semi-axes of the planet at mean distance.

These values for the size of the disc were found from a great many differential measures made in 1880–81, and are somewhat larger than those given by heliometer measures, owing to irradiation, but they will probably better satisfy micrometer work.

In the determination of rotation period, the observations have been corrected for longitude of equinox, aberration time, annual parallax, and defective illumination. With the exception of the longitude of equinox, all the other corrections have been taken from Marth's Ephemerides.

The time used is that of the 90th meridian west from Greenwich.

The Great Red Spot.

The following rotation periods will indicate the motion of the great red spot since last year:—

1890 July 1 to 1890 Dec. 8, (160 days),

$R = 9^h\ 55^m\ 39^s\cdot75$

1890 July 1 to 1891 May 25, (328 days) 39·96 secs.

1890 Dec. 8 to 1891 May 25, (168 „) 40·10 „

1891 May 25 to 1892 Jan. 22, (242 „) 41·27 „

These numbers indicate that the spot has not yet ceased to retrograde.

During the past opposition the "mean" period $41^s\cdot27$ does not satisfy the observations, but a uniformly retarded velocity represents the motion fairly well. I have given in col. 4 the residuals (Observation—Ephemeris) for a uniform rotation $41^s\cdot27$, and in col. 5 the same for a retarded motion, $R = 9^h\ 55^m\ 40^s\cdot0$

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$+n \times 0^{s}\cdot005$, in which n equals the number of rotations from the epoch 1891 May 25.

For a uniform rotation period the "mean" residual (Obs.—Eph.) is ± $1^{m}\cdot7$, and for a retarded rotation ± $1^{m}\cdot2$.

T = Time of passage over the central meridian.
L = Length of chord on middle of disc.
B = Breadth.
β = Apparent latitude.

The length of the great red spot appears to be about $1''$ shorter than in former years. In 1890 the length from two measures was $11''\cdot49$. In 1889 the spot was too indistinct for reliable measures of length.

The Great Red Spot.

Date		Days	T	$41^{s}\cdot27$ Obs.-Eph.	$40^{s} + n \times 0^{s}\cdot005$ Obs.-Eph.	L	B	β
1891			h m	m	m	$''$	$''$	$''$
May	25	0	14 29·7	+2·7	+1 0	...	...	...
July	5	41	13 20·8	+1·0	+0·9	...	...	−7·21
	9	45	16 38·4	+2·1	+2·1	10·24	4·09	6·63
	14	50	...	...	...	...	3·83	7·00
	20	56	10 38·9	−3·8	−3·4	10·36	4·69	6·84
	22	58	12 19·2	−1·7	−0·7	11·18	...	...
	26	62	15 32·9	−4·3	−3·7	...	...	7·09
Sept.	6	104	10 13·0	−0·1	−0·1	...	...	...
	9	107	7 39·8	−2·2	−1·3	...	...	6·35
	11	109	9 20·1	+0·2	+1·2	...	...	7 19
	16	114	8 22·1	−5·0	−3·9	...	...	7·49
	21	119	7 34·5	−0·1	+0·8	...	...	7·30
	3	121	9 12·4	−0·3	+0·4	9·85	4·95	...
	25	123	10 51·6	+0·7	+1·4	10·48	4·50	6·82
Oct.	5	133	9 07·4	+0·9	+1·8	...	...	7·27
	7	135	10 44·9	+0·1	+0·9	...	...	7·30
	22	150	8 08·8	−0·8	−0·3	...	...	7·08
	27	155	7 18·7	+0·5	+0·8	...	...	6·56
Nov.	17	176	9 42·4	+1·1	+0·9	...	...	6·68
	30	189	5 34·4	+2·9	+0·5	...	...	6·54
Dec.	29	218	4 41·3	+2·6	+0·5	...	...	7·13
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Jan.	22	242	4 41·6	+3·5	+0·0	...	...	...

Mean Length ... $10''\cdot42$ (5 obs.)
„ Breadth ... 4·41 (5 obs.)
Reduced Latitude −6·52 (17 obs.)

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Dark Spots on B_6.

During the opposition of 1891, three separate spots were observed on this belt, two of which were distinctly red in colour and of considerable length. The third spot appeared as a dusky hazy patch, and was $0''\cdot7$ farther south.

The rotation periods for these objects were $9^h\ 55^m\ 20^s$ and $9^h\ 55^m\ 0^s\cdot3$.

Long. Red. B_6.

$R = 9^h\ 55^m\ 20^s$.

Date.		Days.	T		Obs.-Eph.	L	B	β
1891.			h	m	m	″	″	″
July	3	0	16	41·7	−2·4	...	...	−8·23
	8	5	15	48·8	+1·0	7·26	...	9·02
	15	12	16	30·7	+3·0	7·67	1·05	9·59
	28	25	11	59·6	−1·7	...	...	9·20
Sept.	7	66	10	10·5	−1·2	7·91	1·03	8·54
	15	74	6	45·1	+3·8	...	...	8·66
	22	81	7	22·3	+1·4	...	...	8·80
	24	83	8	57·0	−0·3	...	...	...
	29	88	7	56·8	−4·1	7·49	1·31	8·63
Oct.	9	98	6	12·0	+3·6	...	...	...
	16	105	6	48·0	−1·1	...	...	...
	28	117	6	32·7	−2·0	...	...	...

Length ... ... $7''\cdot58$ (4)
Breadth ... ... 1·13 (3)
Reduced Latitude −8·34 (8)

Long. Red. B_6.

$R = 9^h\ 55^m\ 03^s$.

Date.		Days.	T		Obs.-Eph.	L	β
1891.			h	m	m	″	″
Nov.	5	0	7	05·6	+0·0	11·00	...
	26	21	8	58·2	+3·3	12·23	−8·64
	18	43	6	35·9	+0·1	...	...

Length ... ... $11''\cdot61$ (2)
Reduced Latitude −8·24 (1)

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Dusky Black Patch. B_6.

$R = 9^h\ 55^m\ 20^s$.

Date.	Days.	T	Obs.-Eph.		β
1891.		h m	m		″
Sept. 10	0	9 33·7	+0·0	...	−9·41
Oct. 9	29	8 05·3	+1·4	...	...
14	34	7 06·2	−1·6	...	9·37
16	36	8 45·9	+1·3	...	9·47
21	41	7 47·2	−1·6	...	9·46
Nov. 2	53	7 36·8	+2·2	...	...
Dec. 18	99	5 09·0	+0·1	...	...

Reduced Latitude − 9″·01 (4)

Dark Spots on the North Edge of the Equatorial Belt.

During the opposition of 1890, from June 12 to October 20, five small reddish black spots were observed on the north edge of the equatorial belt; two of these spots have been observed again in 1891.

The rotation periods for the several spots observed in 1890 were as follows :—

	h	m	s	days
a =	9	55	34·0	130
b =			33·3	179
c =	,,	,,	36·6	70
d =	,,	,,	32·0	108
e =			36·6	7

The spots a and b were observed in 1891. The mean longitude of b with reference to a was as follows :—

	m
1890	+40·2
1891	+24·8

The following are the rotation periods for the spot a :—

1890 June 12 to 1890 Oct. 20	130 days	
	$R = 9^h\ 55^m\ 34^s{\cdot}0$	
1890 Oct. 20 to 1891 July 9	262 days	$31^s{\cdot}4$
1891 July 9 to 1891 Nov. 5	119 ,,	$27^s{\cdot}4$

These numbers indicate a pretty uniform decrease in the rotation period.

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Spots a and b, North Edge of Equatorial Belt.

$R=9^{\mathrm{h}}\ 55^{\mathrm{m}}\ 27^{\mathrm{s}}{\cdot}4$

Date.		Days	T	$b\,\Delta\,t$	Obs.-Eph.	β
1891.			h m	m	m	″
July	9	0	14 01·1	...	+0·0	...
Sept.	8	61	8 43·3	22·6	+1·7	+4·36
	10	63	10 17·3	23·8	−3·0	...
	15	68	9 23·8	25·0	+0·9	...
	25	78	7 37·4	25·7	+5·1	4·17
	29	82	10 45·3	27·8	−1·1	...
Oct.	2	85	8 13·8	25·8	−0·4	...
	9	92	8 54·5	26·2	−2·1	3·87
Nov.	2	116	8 33·6	21·9	−0·4	...
	5	119	6 01·8	...	+0·7	...

Mean difference of Longitude *a* and *b*, $24^{\mathrm{m}}{\cdot}8$

Reduced Latitude $+4''{\cdot}67$ (3)

Small Black Spots on B_2.

A number of small black spots were seen in reduced latitude $+9''{\cdot}34$, but accurate longitudes were not determined. In 1880, from August to October, two small black spots were observed in latitude $+11''{\cdot}0$. The rotation periods were $9^{\mathrm{h}}\ 55^{\mathrm{m}}\ 31^{\mathrm{s}}{\cdot}0$ and $40^{\mathrm{s}}{\cdot}5$ respectively. See Report of the Dearborn Observatory, 1881.

Small Black Spots on B_3.

During the past opposition a great number of small black spots were seen on the south margin of this belt, appearing like a row of beads, making it difficult to identify individual spots. The longitudes of three of these spots, the first of a row, were accurately determined on two successive nights, and when compared with Marth's Meridian II. they indicated a gain of $7^{\mathrm{m}}{\cdot}5$ daily, or a rotation about 3^{m} less than the great red spot.

The following are the times of transit:—

	h m	h m	h m
Sept. 7	11 14·1 (*a*)	11 30·7 (*b*)	12 03·1 (*c*)
Sept. 8	6 56·5 (*a*)	7 14·6 (*b*)	7 47·8 (*c*)

Additional spots:—

	h m	h m	h m
Sept. 8	8 06	8 23	8 36
,,	8 57	9 27	9 52

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Latitude observed :—

Sept. 7	+6″·11	Sept. 25	+6″·34	Oct. 9	+5″·64
Nov. 24	+6·15	Dec. 11	+6·06		

Reduced Latitude + 6″·56 (5 obs.)

I observed spots on this belt in 1880–84.

Elliptical White Spots on B_6.

During every opposition since 1880 elliptical white spots have been observed on a belt just south of the great red spot. These spots usually have a drift in the direction of the planet's rotation when referred to the great red spot.

The spots whose longitudes were determined in 1891 had a direct motion of about 0$^{\text{m}}$·9 daily.

The following transits have been observed :—

Date.	T	β	
1891.	h m	″	
Sept. 25	9 47·5	−9·10	Group of spots.
25	10 01	...	
25	10 16 (*c*)	...	
25	11 02·3	...	
Oct. 22	9 01·4 (*a*)	−9·12	
27	8 01·7 (*a*)	−9·25	
29	7 53·4 (*c*)	...	
Dec. 29	4 24·0 (*a*)	...	

Reduced Latitude − 8″·71 (3)

On the south margin of B_6, in reduced latitude − 10″·7, elliptical white spots have been observed at every opposition since 1880. These spots are the most difficult of any of the markings visible on the planet, and can only be seen under favourable atmospheric conditions. The rotation period deduced from them is approximately the same as for the great red spot. In 1883, however, they had a retrograde drift of 1·2 degrees daily, or a rotation period 50 seconds greater than the great red spot.

Equatorial White Spots.

The equatorial belt was usually mottled with white spots on both the northern and southern portion, but none of the spots were particularly conspicuous.

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Date		Days	T		Obs.-Eph.	β	Remarks.
1891			h	m	m	″	
July	8	...	15	34·3	...	−2·32	Double Spot
	9	...	14	50·9	...	+2·19	Double Spot
	15	...	16	18·5	...	−3·30	
	15	...	16	04·0	...	+2 (est.)	
Sept.	10	0	9	43·5	+ 0·0	+2·20 (*a*)	
	10	...	9	57·9	+ 0·0	−3·32 (*b*)	Spot foll. $8^m·6$, 0″·5 south
	29	...	8	22·0	...	+2·01	
Oct.	16	...	9	00·0	...	−3 (est.)	
Nov.	2	53	7	30·9	+ 12·0	+ 1·48 (*a*)	
	2	...	7	30·9	+ 9·0	−3·00 (*b*)	
	18	69	7	11·0	− 0·9	+ 1·95 (*a*)	
	18	...	7	11·0	− 0·9	−1·43 (*b*)	
Dec.	18	99	5	35·1	− 7·7	−2·20 (*b*)	

The approximate rotation periods are

$a = 9^h\ 50^m\ 31^s·6$, 69 days, Reduced latitude +2″·67 (3)

$b = 9^h\ 50^m\ 26^s·4$, 99 „ „ „ −2·00 (4)

The motion was not uniform.

The Equatorial Belt.

During the past two years the great equatorial belt has been quite open. At times, however, a faint marking has extended over the middle portion. The approximate width of the open part in 1890 was 2″·6, and in 1891 3″·1, or about one-third of the total width of the belt.

During the past thirteen years the belt has usually been separated in two portions by a rift, but at times, notably in 1879 and 1880, the belt was made up of three nearly equal portions, the central one being midway between the other two.

In the observations which follow, the 2nd col. is the approximate longitude in time, from Marth's Meridian II.; 3rd col., position angle of the north edge of the belt; 4th col., comparison with Marth's ephemeris for *Jupiter's* equator; 5th col., apparent latitude of the north edge; 6th col., width of the belt.

The comparison with the ephemeris indicates that the north edge of the belt was parallel to *Jupiter's* equator.

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The Equatorial Belt.

Date.		Long.	P	Obs.-Eph.	β	W
1891.		h	°	°	″	″
July	3	+3·3	64·1	−0·7	+3·76	9·31
	8	+4·3	63·6	−1·2	3·60	8·80
	9	−1·5	...	...	4·19	...
	14	+0·0	64·4	−0·4	...	...
	15	+3·7	65·1	+0·3	3·21	9·11
	20	+0·6	67·1	+2·2	3·40	9·98
	23	−3·5	63·6	−1·3	3·74	...
	26	+0·0	65·6	+0·7	...	...
Sept.	8	−3·7	65·2	−0·1	4·36	7·93
	21	+0·5	64·2	−1·3	...	...
	25	−2·3	65·5	−0·0	4·17	7·16
	29	−5·8	65·8	+0·2	...	9·30
Oct.	7	−0·3	66·4	+0·7	3·67	7·88
	9	+1·5	...	...	3·87	...
	20	+1·6	65·3	−0·5	3·78	9·51
Nov.	2	−4·0	65·9	+0·1	...	...
	24	−2·0	...	...	3·49	7·67
	26	−3·8	67·1	+1·4	...	8·22
Dec.	11	−1·5	65·7	+0·2	3·13	7·96
	18	−4·5	64·3	−1·1	...	...
	29	+0·5	64·8	−0·5	...	...

Inclination of the North Edge of Equatorial Belt to Equator = −0°·07

Reduced Latitude	+4″·25	(13 obs.)	
” ”	+4·79	(13 obs.)	1890
Mean Width	8·57	(12 obs.)	
” ”	10·42	(9 obs.)	1890

Theory of Jupiter.

In my annual Report of the Dearborn Observatory, 1881, I gave the following hypothesis—viz., “That the surface of the planet is covered with a liquid semi-incandescent mass, that the belts, the great red spot, etc., are matter at a lower temperature. Over the liquid surface is an atmosphere, in which is formed the equatorial white spots, which are of the nature of clouds.”

I still think that the lower surface of the planet is of the nature of a liquid, but not necessarily hot.

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Observations of the Reappearance of the Rings of Saturn; Observations of the Position-Angles of the Rings, and Observations of the Satellites. By E. E. Barnard.

The conditions for observation at the reappearance of the rings of *Saturn* in 1891 were somewhat better than those at the disappearance in 1878. Neither the reappearance of 1878 nor the disappearance of 1891 could be observed on account of the proximity of the planet to the Sun.

At the present reappearance of the rings, the planet was situated in the morning sky, two hours and a half west of the Sun, and in three and a half degrees north declination.

From Professor Hall's valuable memoir on *Saturn* (being Appendix II. of *Washington Observations for* 1885) we learn that with the 26-inch the rings were wholly invisible at the disappearance of 1878, except where they were projected on the ball of the planet. Since the reappearance of *Saturn* from the region of the morning Sun, I have examined it carefully a number of times with the 12-inch, and on two occasions, when the opportunity permitted, with the 36-inch.

Up to October 29, on no occasion, with the most careful scrutiny and good seeing, was it possible to detect the slightest trace of the rings projected on the sky, though they appeared as a heavy black band crossing the planet and apparently cutting it nearly in halves.

On October 22 *Saturn* was carefully examined with the 36-inch, but the rings were equally invisible in that instrument. The observations extended from $17^h\ 15^m$ to $18^h\ 15^m$ Standard Pacific time (8^h slow of Greenwich). The seeing was 3 on a scale of 5 for perfect steadiness. The projection of the ring on the ball was perfectly black. The edges were sharp and perfectly free from irregularities, and no evidence of the crape ring was seen. The southern edge of the trace was slightly convex. Only one belt was visible, and that was some 3″ south of the ring.

I very carefully measured the width of the projection of the ring at its middle part on the ball. This could be done with great accuracy by placing the wires so that their outer edges exactly filled the black trace, the measures being corrected for the thickness of the wires (0″·12). The resulting value, at $18^h\ 0^m$, gave the width of the middle of the projection = 0″·51. This agrees exactly with the value derived from the data in the American Ephemeris (0″·51).

The measured distances of the centre of the projection from the polar limbs of *Saturn* were

From north limb = 7″·40
From south limb = 6·56